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A CURRENT ASSESSMENT OF SINGLE SITE LOCATING TECHNOLOGY

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ABSTRACT

This paper describes the observed performance of a HF Single Site Locator (SSL) which employs current interferometer technology. 142 locations were obtained from non-cooperative targets over a five day period in April 1989. Locations were determined from fast, high resolution azimuth and elevation angle of arrival measurements and a knowledge of the ionospheric reflecting medium. Exact emitter locations were determined post facto with ground truth data from the field units. Five modes of transmission were encountered and the signals were successfully located. Miss distance accuracies varied between 12.5 kilometers to 40.5 kilometers over ranges that varied from 109 kilometers to 526 kilometers. Performance varied as a function of modulation type with SSB voice being the most difficult to prosecute and packet and burst signals were the easiest to locate. Also performance varied as a function of range and the relationship of the operating frequency to the maximum usable frequency between the SSL and the target.

I. INTRODUCTION

HF radiolocation will remain important to the surveillance community through the next several decades. Use of the HF spectrum continues to expand, especially in third world countries. The number of emitters will increase and the use of more exotic modes of transmission is also expanding. From the surveillance point of view, the HF signal location scenario for the next decade is one in which high interest regions will change as new crises arise. The areas where signals of interest (SOI) will originate will be smaller so signal search can be more focussed. A key element in future direction finding is expressed by the term "rapid deployment." Smaller, tactical systems that are easily transportable will replace the large shore-based direction finding networks.

Single Site Location (SSL) technology was first conceived in the late 1960s. However, its initial development was overshadowed by the large shore-based and smaller shipboard netted systems. In those systems, signals were located by triangulation using multiple lines of bearing. But recent events have revealed that the present netted-sensor concept lacks mobility and flexibility, both of which are noteworthy attributes of SSLs. In the 1970s, early testing burdened SSL technology with a "10% of Range" accuracy specification. And in the early 1980s, systems developed and tested by the research community were lacking in performance. Furthermore, a lack of awareness of the real reasons for this breakdown in SSL performance compromised their further advancement. Tests had indicated that signal sampling rates had to be higher and propagation effects had to accounted for. Attempts to develop the next generation system failed to capitalize on history, and since then SSL as been, in general, ignored as a practical radiolocation technology by the majority of the HF surveillance community.

Nevertheless, recent advancement of SSL capabilities has been achieved through cooperative programs and in-house research. This paper describes the results of one such exercise conducted by personnel from the Naval Command Control and Ocean Surveillance Center (NCCOSC), RDT&E Division (formerly, Naval Ocean Systems Center) in San Diego, California in 1988.

Transionospheric refractive effects were measured at 30 MHz by comparing the direct elevation angle of arrival of signals from an orbiting HF beacon with the accurately known altitude/location of the satellite. The angle of arrival measurements were made with the Single Site Locating Testbed at Southwest Research Institute (SwRI) in San Antonio, Texas. The transionospheric work had required upgrades and calibration of the 7-channel interferometer which had been originally designed as an SSL. It was desired to demonstrate that these modifications had improved the SSLs capabilities against terrestrial HF signals as well.

In April 1989, the exercise described here was conducted with the SwRI SSL. A completely independent communications exercise was being conducted in Texas by another facility which provided numerous, different types of signals. Many signals of opportunity offered a good chance to evaluate the performance of a modern single site locator in a non-cooperative signal environment. Modulation types were a mix of older, more familiar modes and newer modern digital schemes. This also provided the first opportunity to make SSL measurements of digital burst and packets signals. The data were considered non-cooperative in that the locations of the SOIs were not known in advance of the measurement period. Also their transmission schedules were not known.

II. DESCRIPTION OF THE SINGLE SITE LOCATING TESTBED

Radiolocation with a single station location system includes an azimuth measurement on the target's signal and an estimate of the target's great circle range based on ionospheric parameters measured at the SSL site. The system combines azimuth and range to the target to produce the targets location. This is also expressed in

the corresponding geographic coordinates as illustrated in figure 1.

Figure 2 illustrates the essential concept of SSL system operation. An HF radio wave transmitted from a target transmitter reflects from one or more reflecting regions in the ionosphere. The radiowave propagated by each mode arrives at the SSL site with a given bearing and angle of elevation. A radio direction finder measures the azimuth and elevation of the arriving signal.

The SSL system includes an ionospheric sounder which measures the virtual height of the ionospheric reflecting region. The reflection height measured at the SSLs location is assumed to be the same as at the reflection midpoint. As shown in figure 2, the triangle from the SSL site through the ionospheric midpoint and down to the target transmitter provides a location estimate. This calculation generates a range estimate (in kilometers) and combines it with the observed azimuth bearing. The SSL system output is thus an estimate of the location of the target producing the signal expressed in geographical coordinates. This is in contrast to a conventional direction finder which provides only an azimuthal line of bearing to the target signal.

The range calculation uses the measured elevation and virtual height of the ionosphere, along with the law of cosines, to determine the angle at the center of the earth from the midpoint (half range) to the SSL system. This angle, when multiplied by twice the earth radius, gives the great circle range from the SSL site to the target.

Figure 3 shows the fundamental system components of the SwRI SSL system used for the tests described in this report. The computer interfaces both to the phase-measuring interferometric direction finder and to the ionospheric sounder. The antenna system has two parts, a low band array (3-10MHz) which is 150 meters on a leg and a high band array (10-30 MHz) which is 50 meters on a leg. Both arrays are in an "L" configuration using seven crossed loop elements. The azimuth and elevation angles of an incoming HF signal were calculated using a phase linear concept. SwRI refers to this concept as a coincidence direction finding interferometer. In this type of system, the phase linearity is tested on the resolved long baseline phase for each leg of the SSL antenna array. If the differences between the predicted and measured value on both baselines are less than some preset value, then the data frame becomes a coincidence frame, one in which the array has resolved the angle of arrival (AOA) of the signal.

In single site locating, operator functions were to search and identify a signal of interest, optimize receiver tuning, and start and terminate the direction finding process. Automatic functions of the system include computing the target azimuth and elevation angles of arrival, measuring the ionospheric height, generating an elevation angle/range transmission curve and computing the best point estimate (BPE) of the target location. Figure 4 shows the operator display on the present SSL Testbed. Once the operator has selected a SOI, he presses the "execute" button initiating the scanning process on the array. The azimuth and elevation are displayed for every frame that passes the phase linearity test. When the operator decides there are sufficient data to calculate a fix, the computer is switched to the "location" mode. Then the elevation cursor is placed on the range transmission curve to achieve a "range" solution. The azimuth angle of arrival calculation is automatic and requires no operator intervention. After completing the calculation of the range and azimuth angle, the computer generates the target's geographical coordinates. There is no way for the system to distinguish between a one- and a two-hop signal. Therefore the system generates both solutions, leaving the decision up to the operator.

In the past, there have been three issues which have a significant impact on the accuracy of an SSL. These are (1) the assumptions made in the BPE calculation; (2) the assumption that the signal propagates along the great circle path at short ranges; and (3) the interval at which the ionospheric data needs to be updated.

The assumptions made in the BPE calculation lead to three weaknesses. The assumptions are: (1) that the operator will place the elevation cursor on the correct elevation angle and will do so "properly"; (2) that the transmission curve calculation generated from the vertical ionograms, is correct and current; and (3) that the ionospheric height at the path midpoint is approximately the same one measured locally.

Near vertical incidence propagation refers to skywave propagation between 100 and 500 kilometers. It has long been thought that near vertical incidence signals inside 100 kilometers will not produce reliable AOA information. A primary assumption in SSL is that the ionospheric reflection point is along the great circle path at the midpoint. Experimental evidence (Paul, 1985) indicates that the skywave reflection point wanders from several kilometers to tens of kilometers from the great circle path. For ranges greater than 500 kilometers, this represents a negligible error whereas inside 500 kilometers errors are significant and inside 100 kilometers they are intolerable. Also for ranges of less than 100 kilometers where the elevation angles are greater than 82 degrees, the arctangent function for the angle of arrival equations becomes very unstable. While it is recognized that tilt correction techniques exist, they have yet to be fully demonstrated in a realistic operating environment.

The ionospheric profile has to be updated at a rate which will maintain acceptable SSL accuracy because the maximum correlation time between ionospheric measurements is 5 minutes (Rose, 1988). One objective of this experiment was to see whether increasing the number of ionospheric measurements over a given period of time had any impact on the accuracy of the fix.

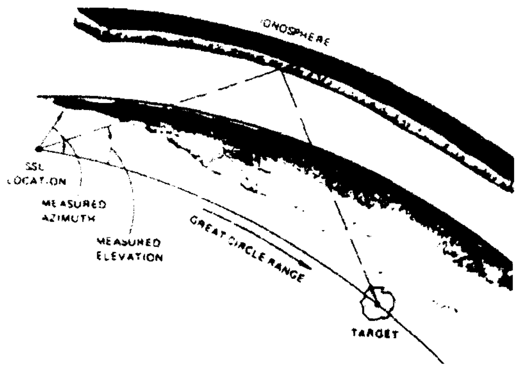

Figure 1. Single Site Locating Concept

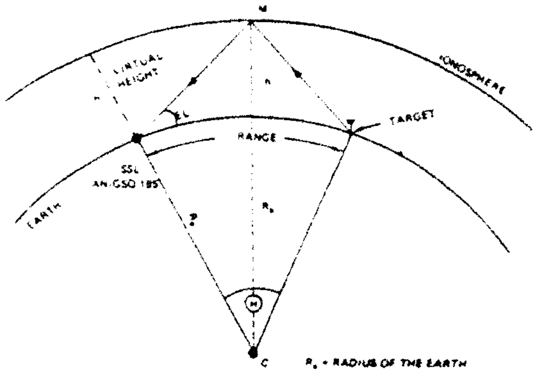

Figure 2. Range Estimate Geometry

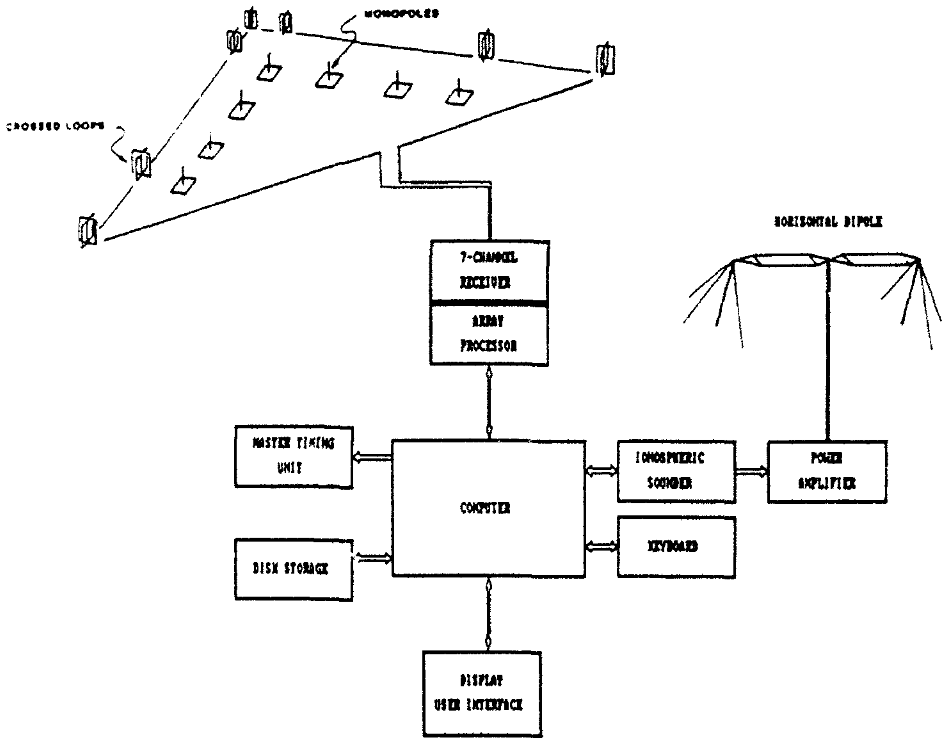

Figure 3. 7-Channel Single Site Locator Instrumentation

III. DESCRIPTION OF THE FIELD TEST DATA COLLECTION

Data collection for this test occurred between 20 and 25 April 1989. During this period, solar conditions were relatively undisturbed. The 10.7 cm flux varied between 173 and 198. The magnetic A-index was low, ranging from 8 to 14. At midday, the F-region critical frequencies were exceeding 15 MHz which means that the 3000 km maximum usable frequency exceeded 50 MHz. Generally propagation conditions were excellent.

The frequencies used were known before hand. The operating schedule and the mode of transmission were unknown. Thus, scanning the allocated frequencies was required to locate the signals which were part of the experiment. Ground truth location data could be obtained after the fact. While this approach may appear rather "hit or miss," only a day of monitoring was required to establish the frequencies used and the general locations of all the participants in the experiment.

The five day collection period produced locations for 142 signals. After finding a SOI, the system was activated. Throughout the test period, the ionosphere was measured and data processed automatically and stored in the computer data files. A key issue was the speed with which the SSL could acquire a signal, gather data and generate a fix. After learning the mechanics of the testbed, the entire process could be accomplished in a matter of seconds. At no time were there more signals than the testbed could prosecute, and all signals prosecuted produced a fix. All of the data collected were reported. The SSL testbed was never stressed by saturation. In fact a major concern was the relative lack of signals to prosecute. An entry for the signal call sign, event number and signal characteristics for each signal prosecuted were manually entered in the operator log. When the computer provided the BPE for the event, the hardcopy output was also taped in the log as was all the related data for each event. These data were then used to reconstruct skywave propagation conditions that could influence SSL accuracy.

After the field test, "ground truth" data were obtained on the locations of the mobile and fixed emitters. With these data, and the information in the operator's log, casecards were constructed for each of the 142 fixes. The casecard software, written during the 1986 experiments, allows the user to determine the accuracy of the SSL fix product. For this exercise, the casecard data were entered into Lotus 123 spreadsheets for analysis. The next section presents results from these analyses.

IV. PRESENTATION OF THE DATA

The experiment produced 142 location fixes on signals that varied in range from 95 kilometers to 528 kilometers. Before this exercise there was very little quantitative data on SSL performance on short path (under 500 Km) skywave signals. The experiment encountered five different modulation types:

(1) Four Second Digital Burst - 40 fixes
(2) Digital Packet (encrypted) - 29 fixes
(3) Upper Sideband (USB) Voice - 24 fixes
(4) Amplitude Modulation Voice - 28 fixes
(5) Morse (18 groups/minute) - 21 fixes

In addition to SSL accuracy, other issues to be studied during this exercise, were operator experience, display interpretation and the user interface. The operator had a broad experience in SSL development, direction finder operation and HF propagation and modeling. The accuracy of the present SSL concept relies heavily on operator judgement and his understanding of what is being displayed. It was desired to gain enough experience with these issues in mind to develop expert systems to automate some of these processes in the future.

An early observation in this experiment was that each signal modulation type produces very different data clustering on the operator display. This in turn affects the difficulty in placing the range cursor and the accuracy of the location estimate. Figure 5 shows examples of four of the modulations encountered and the type of presentation the operator had to contend with.

The encrypted digital packet signals were very easy to find, even in a high interference environment. These signals were also easy to fix and produced a very high phase linear ratio. However, they all came from a single location 95 kilometers away and the short range caused severe azimuth spreading. This badly corrupted the results from this one site.

By far the most difficult conventional narrowband signal to prosecute with the present system is single sideband, suppressed carrier (SSBSC) voice. Because the received power varies as a function of the speech envelope, the signal presents a variable signal to noise, to which the system must constantly be adjusting. Very low (below 20%) phase linear ratios are quite common with this mode of transmission. For this reason, SSB signals normally require 30-60 seconds of collection time to acquire a sufficient sample to process. It is very frustrating for a SSL operator to listen to a signal that is very loud and very easy copy to the ear and yet see the phase linear sample count not increasing. This could be rectified with more sophisticated processing in the next generation system. The example in figure 5 shows an unusually good example of upper sideband (USB) voice as it appeared to the SSL operator. Normally the displays were much sparser.

Amplitude Modulation (AM) voice signals provide a continuous carrier which provides in a stable signal to noise ratio and therefore is a relatively easy signal for the SSL to prosecute. Normally, 10 seconds will provide a phase linear sample sufficient to locate the signal. Figure 5 illustrates how the AM signal appears on the SSL display. In this example it took 10 seconds to acquire 487 samples.

Figure 5 also shows how on-off keyed

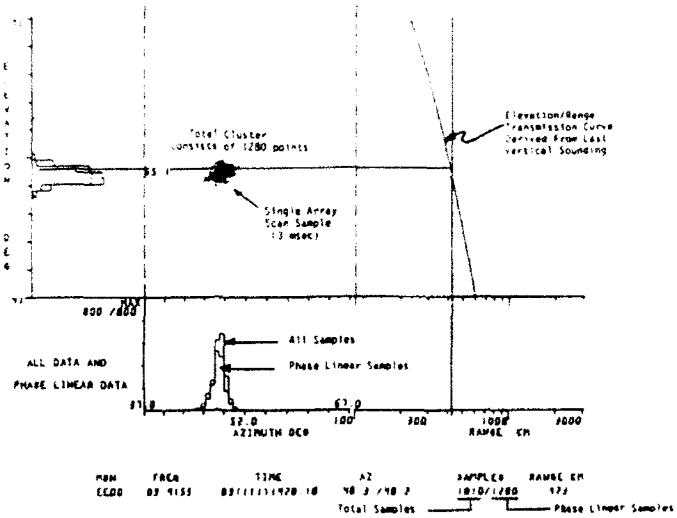

Figure 4. SSL Azimuth/Elevation Operator Display for an USB Voice Signal

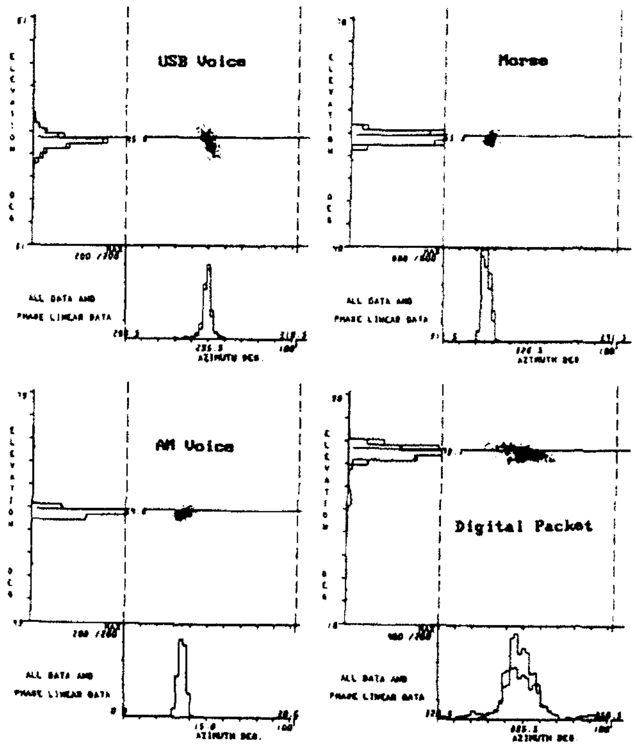

Figure 5. Scope Presentations for Different Modulation Modes

Morse signals appeared to the SSL test bed. In the example shown it took 90 seconds to acquire approximately 2000 samples. At reasonable on-off keying speeds(i.e.15-25 code groups per minute), this mode of transmission presents a very stable signal to noise making it one of the easiest signals to locate. Experience has shown that any part of a morse transmission produces a usable location product. In most cases the accuracy of the 3 second fix was the same as the 90 second fix. It was possible to get good fixes on single dots or dashes.

Table 1 summarizes the SSL performance by modulation type. One commonly used measure of SSL performance is the miss distance, the distance between the BPE and the true location of the target. This can be expressed in linear distance (kilometers in this case) or as a percentage of the true range between the SSL and the target. In this latter case, the performance measure normalizes out the differences in baseline ranges. Review of all of the fix data indicates that 26 (18%) of the fixes had miss distances of less than 10 kilometers, 78 (52%) had miss distances of less than 20 kilometers and 106(75%) had miss distances of less than 30 kilometers. This is quite good considering the short ranges of the data used for this study.

Figure 6 shows how location azimuthal accuracy degrades as range decreases. A signal from 423 kilometers presents an azimuthal dispersion of approximately 6 degrees whereas a signal from 160 kilometers is spread over 30 degrees. The longer range produced a better location fix, one with a lower variance. On the other hand, the very short range produced a location fix with a very high variance which can be interpreted as very low confidence in the result.

V. DISCUSSION

The exercise described in this report provided new insight on two digital signals, the short burst and the packet, that had never been prosecuted before with this SSL and short baseline ranges of between approximately 100 and 500 kilometers. The measurements resembled a tactical situation against uncooperative signals whose location was unknown at the time. While the upgraded seven channel interferometer samples signals and makes an AOA measurement very rapidly, the user interface was not modernized and presented a less than optimum situation. Although the operator for this test had extensive experience in the areas of HF direction finding, SSL development and HF propagation, interpretation of the display was still often complicated. Therefore the performance results, while considered good, can be improved.

The four second digital burst communication mode provides the interferometer with an optimum signal. This mode is extremely easy to prosecute and, at ranges of greater than 300 kilometers, it is easily located. As the range decreases below 300 kilometers, that accuracy of SSL fixes degrades. Indeed, at these the shorter ranges (<300 km) ,such signals are actually harder to locate accurately than signals with a higher duty cycle. Because of their short duration, the AOA from a burst signal is vulnerable to any shifts in the reflection point from great circle. The result presents the user with an easily heard and usually loud signal, as well as optimum azimuth and elevation displays with very small standard deviations and a definite, but wrong location solution.

During the experiment, the time between ionospheric soundings was varied. At the times of the day when the sun was low in the sky, updates were needed every 10 minutes to keep fix accuracies between 5% and 10% of range. During midday and at night, sounding every fifteen minutes was sufficient. When the ionospheric data were updated hourly, the performance degraded to 10% to 15% of range. Historically, hourly updates have been the norm.

VI. CONCLUSIONS

Single site radiolocation at HF is a good technology for signal sources located between 100 to 1500 kilometers. Future conflicts will require a quickly deployable intelligence gathering system in which radiolocation is an important function. SSL can do this. Over the last several years the new improvements in various components in this technology have been demonstrated by one means or another. It is now time to design a well thought out system that takes advantage of the latest advances in computer systems, intelligent user interfaces using expert systems and modern ionospheric sensing.

The data reviewed indicate that the performance of the SSL is influenced by the transmission mode. The mean miss distances varied from 12 kilometers to 40 kilometers which represents a variation between 6 % and 11.0 % of range. It is estimated that a next generation SSL can achieve 5.0% of range accuracies if the user interface and the vertical sounder are modernized and

Table 1. Summary of SSL Accuracy Performance

Modulation	Mean Miss Distance (km)	Mean Miss Distance (% of Range)	Mean Azimuth Error (Deg)
Burst	22.3	6.0	1.1
Packet	12.5	8.3	-0.3
USB Voice	40.5	11.0	1.1
AM Voice	24.0	7.7	-1.3
Morse	23.4	7.4	-1.8

made smarter. It must incorporate more collateral information about the intended targets. Finally, the next generation system needs some sort of propagation mode identification.

The experimental data presented in this report provides a glimpse of how good single site locating can be today and also, provides direction for improvement. An earlier HF radiolocation experiment established that the baseline accuracy of the SwRI seven channel interferometer testbed is 1.0% of range without the errors induced by the ionosphere. This is likely to be close to the physical limit of a SSL when it is prosecuting terrestrial targets since the earlier measurements were made just before sunrise when the ionospheric electron density is at its minimum.

The requirement of high quality real time vertical sounding data for the range solution is critical to the SSL process. This experiment confirmed earlier work that the performance of the system is heavily dependent upon (1) the experience of the operator and (2) the use and interpretation of the user interface. SSL performance has been in the past and remains today very "user intensive." The next generation SSL should have an "intelligent" user interface to assist in the data interpretation and decision making.

The ionospheric sounding process needs the following improvements: (1) ionospheric sensing should be sped up, updating the ionogram every two minutes. Experimental evidence indicated that the ionosphere is more variable than current models show; (2) the transmitted signal use spread spectrum techniques to reduce interference; (3) the ionogram interpretation and range/elevation angle transmission curve needs to be modernized through the use of an expert interpreter system; (4) the sounder operation and interpretation must be transparent to the user.

ACKNOWLEDGEMENT

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REFERENCES

Rose, R.B., "High-Resolution HF Time of Arrival measurements (1981-1985)," Radio Science, Vol 23, Number 3, May-June 1988

Paul, A.K., "F-Region Tilts and Ionogram Analysis," Radio Science, Vol.20, Number 4, July-August 1985

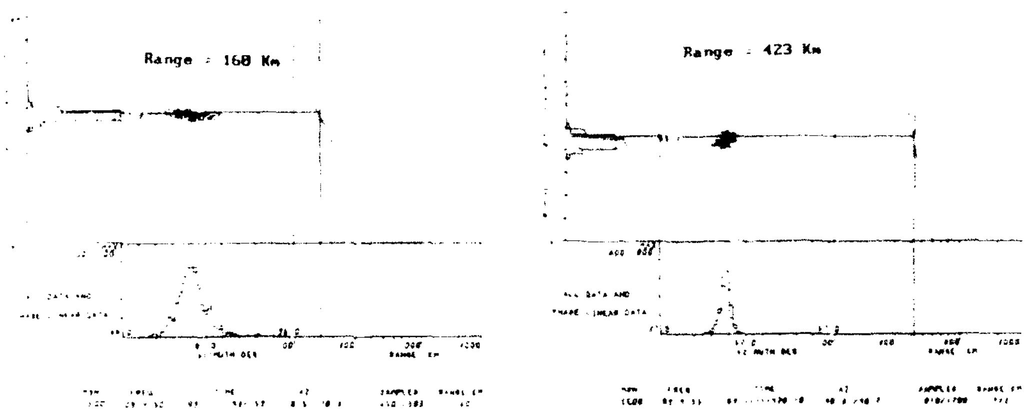

Figure 6. Comparison Between a Very Short and Medium Range SSL Fix. Modulation Mode is a Four Second Digital Burst.

DISCUSSION

H. SOICHER
Since ionospheric conditions are updated by a vertical sounder, what assumptions do you make about horizontal variations of the ionosphere?

AUTHOR'S REPLY
It is assumed, based on work by Charles Rush, that the correlation distance of an ionosonde measurement is roughly 500 km which practically limits it to tactical targets with ranges of less than 1000 km. For the test conducted, the target ranges were between 100 and 500 km, or ionospheric reflection points between 50 and 250 km. At these ranges, I was very comfortable using a local measurement.

G. HAGN
Your data (e.g., Figure 6) illustrate the problem of obtaining good range estimates with the single site location (SSL) method with the interferometer technique on short paths. You mentioned that this method is not practical for ranges less than 100 km without employing a tilt correction. Even with a tilt correction, there may be limitations at short ranges. The MUSIC algorithm, when used with suitable antennas (e.g., the CART antenna described in the Proceedings of the 1990 Tactical Communications Conference, Fort Wayne, IN) can be used to estimate the angle of arrival (AOA in azimuth and elevation). Of course, it is still necessary to have good data on the ionosphere and a good ray tracing model to invert these AOA data to estimates of emitter location. It would be interesting to test the MUSIC approach on short paths (in the steep part of the Ross curve) versus the interferometer method with tilt correction.

AUTHOR'S REPLY
While what you say might be true, I am skeptical about using the MUSIC algorithm in this manner. I have observed the application of MUSIC in many applications over the last decade, and those I have observed have not resulted in a practical, "real world" solution. I should say, I have yet to be convinced that dynamic tilt correction inside 100 km is practical. I have read most of McNamara's and Georges' papers on the subject. Translating these ideas into a practical, useable system is still developmental and not a proven fact. I think the work done so far shows we have a "real" SSL capability at tactical ranges of 1000-100 km. To attempt to do accurate skywave DF inside 100 km (over land) may not merit the added complication.

S. TOWNES
How well did you know the antenna calibration and in an operational system how effective is the calibration?

AUTHOR'S REPLY
The SWRI interferometer antenna system was very tightly calibrated using a helicopter point source. We know the patterns very well. In developing the calibration, experience was gained in learning how the antenna patterns degrade in field operation. If the field interferometer is set up to specification and the heights of each element are accurately known, the antenna degradation ought not be more than 5%.

LEROUX
Quel est l'intérêt du réseau de monopoles? Comment traitez-vous les multirebonds?
What is the benefit of a monopole array? How do you deal with multiple hops?

AUTHOR'S REPLY
The monopole provides uniformity in the antenna pattern. As with any SSL, one must assume single-hop propagation.

J. BELROSE
Would you comment on how to make a covert vertical incidence sounder?

AUTHOR'S REPLY
Actually, there are two methods. First, it is easy to modify the frequency synthesizer to follow a pseudo-random hopping sequence. Instead of a linear sweep, the sounder hops until the ionogram is constructed. We have tried this and it works. Second, we are testing 40 kHz spread-spectrum signals which are undetectable. There is no reason this couldn't be swept in frequency to measure ionospheric height.